

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3422

NOISE SURVEY OF A 10-FOOT FOUR-BLADE TURBINE-DRIVEN
PROPELLER UNDER STATIC CONDITIONS

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SUMMARY

Overall sound-level measurements and frequency analyses of tape recordings of the noise emitted from a 10-foot-diameter, four-blade propeller mounted on a turbine-powered vehicle have been made under static conditions at stations equally spaced on a 75-foot-radius circle. The overall propeller-noise pattern was unsymmetrical about the fuselage center line, the maximum sound-pressure level being located in the right rear quadrant. The frequency analysis shows that this unsymmetrical distribution consists primarily of the two lowest propeller harmonics. In the plane of and ahead of the propeller, harmonics as high as the eleventh are important.

Theoretical calculations of the sound-pressure levels by the method of NACA TN 2968 predict accurately, for the 10-foot propeller investigated, the location of and the maximum levels to be expected for the overall noise and the first two propeller harmonics. The calculations do not predict accurately the location of the maximum sound-pressure levels and the maximum calculated levels are 10 and 13 decibels lower than the maximum measured levels for the third and fourth harmonics, respectively.

The frequency analysis of the recordings obtained at several heights above the ground indicates the presence of a strong reflected wave or waves, other than the ground-reflected wave, that reduced the sound level at the ground as much as 6 decibels. The existence of this phenomenon and the unsymmetrical protuberances about the nose of the airplane which reflect sound waves are possible explanations of the measured unsymmetrical distribution about the airplane center line of the propeller noise.

INTRODUCTION

The aviation industry is endeavoring to find ways of suppressing the noise output of propeller- and jet-driven aircraft without limiting in certain areas the performance and operation of these aircraft. In the vicinity of the airports, for example, noise emitted from aircraft on the ground and during take-offs and landings is of particular concern because of the high levels and the duration of the noise.

Research on propellers presents an excellent opportunity to investigate sound levels and directional characteristics of a number of proposed propeller designs expected to be applicable to the high powers and high speeds of future airplanes. The 10-foot propeller investigated in the present report is typical of designs used in today's aircraft and the tip Mach number and power loading investigated are representative of those used in current operations. These results can be used as a basis for comparison with the noise levels and directional characteristics of other proposed propeller designs.

SYMBOLS

b	blade width (chord), ft
D	propeller diameter, ft
h	blade-section maximum thickness, ft
R	propeller tip radius, ft
r	radius to a blade element, ft
β	blade angle, deg
$\beta_{0.7R}$	blade angle at 0.7 tip radius, deg

APPARATUS AND TEST PROCEDURE

For the present investigation, a four-blade, 10-foot-diameter propeller was mounted on a conventional airplane as shown in figure 1. The blade-form curves and pertinent dimension ratios of the propeller are given in figure 2. The powerplant for the propeller is a turbine engine which drives the propeller clockwise at 1,675 rpm at 98 percent (14,000 rpm) of the rated engine speed. Special torque and thrust recording equipment installed in the airplane was used to obtain the horsepower and thrust during the engine operation. The operating conditions were as follows:

Horsepower delivered to propeller shaft	1,250
Engine speed, rpm	14,000
Propeller rotational speed, rpm	1,675
Propeller tip Mach number, M	0.79
Propeller blade angle at 0.7R, deg	19.50

Clearance of ground by propeller, ft	1
Wind from 20° to the right of the nose, knots	7 to 10
Temperature, °F	47
Barometric pressure, in. Hg	30.27
Static propeller thrust, lb	2,080

Block diagrams of the recording and analyzing equipment are shown in figures 3(a) and 3(b), respectively. Also used to obtain overall sound-level readings was the General Radio Company type 1551-A sound-level meter.

Sound recordings were taken at stations on a 75-foot-radius circle about the propeller hub. The reference axis is in a plane through the fuselage center line. Except for the recordings made at the one station (270°) at heights of 2, $3\frac{1}{2}$, and 5 feet above the ground, all recordings were made at ground level. The location selected for the sound measurements was a concrete apron with no buildings or other reflective surfaces within 300 yards. Because of the limited ground running time of the engine, measurements of sound levels by the sound-level meter were not obtained at all stations on the 75-foot-radius circle.

Calibration of the recording and analyzing equipment was accomplished by applying a signal voltage from the audio oscillator shown in figure 3(a) across the microphone leads at controlled frequencies of 100, 300, 500, 1,000, 5,000, and 10,000 cycles per second. These calibration signals were recorded in the field immediately after the sound measurements were made and were used to correct the propeller sound records for the frequency response of the recording and analyzing equipment. A separate microphone calibration was made prior to the sound measurements to obtain the voltage output due to the noise level of the microphone. The frequency spectrum of the noise at each microphone location was obtained by passing the tape recordings through the equipment shown in figure 3(b). The power converter and level recorder shown in figure 3(b) are limited to a total range of 20 decibels. An attenuation is selected for each frequency analysis, or part of each frequency analysis, to keep the maximum sound-pressure peaks within the decibel range of the equipment. The lower limits of sound pressure are therefore raised or lowered according to the attenuation necessary for the peak pressures. The overall sound-pressure level at each station was obtained by passing the sound signals through the equipment shown in figure 3(b) but bypassing the frequency analyzer.

RESULTS AND DISCUSSION

Distribution of Overall Sound-Pressure Levels

Overall sound-pressure-level (root-mean-square sound pressure) measurements are shown in figure 4 as the distribution of the sound-pressure levels about the propeller at a 75-foot radius. Included in the figure are the levels obtained from the analysis of the tape recordings, those obtained from the General Radio Company type 1551-A sound-level meter readings, and the theoretical levels based on the first 4 harmonics calculated from reference 1.

The sound-pressure levels indicated by the General Radio sound-level meter and those obtained from the tape recordings agree within 3 decibels. The measured levels shown have an unsymmetrical distribution about the fuselage center line which, because of the scale necessarily used in figure 4, is not readily discernible. The highest levels of noise were measured 15° behind the propeller plane, being 120 decibels at the right rear quadrant and 115 decibels at the left rear quadrant. Ahead of the propeller, the overall sound-pressure level dropped to 107 decibels. The noise-level measurements in the rear of the airplane within 25° of the fuselage center line reached 119 decibels; this value is considered to be the self-generated overall noise level due to the high-velocity propeller and jet blast over the microphone. The theoretical variation of the overall sound-pressure level is within $2\frac{1}{2}$ decibels of the recorded values at the highest levels, 15° behind the propeller plane in both rear quadrants corresponding to measured levels of 115 and 120 decibels in the left and right rear quadrant, respectively. Ahead of the propeller, where the measured value of sound-pressure level was 107 decibels, the theory predicts a sound-pressure level of zero. Theory, however, considers a propeller in free space operating at constant blade loadings with the calculated free-space pressures doubled to account for gross effects of sound reflections. Differences between theory and experiment may be expected because of such effects as variations of pressures on the blades during a revolution that may be the result of inflow dissymmetries. Also, propeller pressure waves reflecting from the ground and the aircraft component parts such as oil inlets, oil cooler ducts, and wings could produce further differences in magnitude and spatial distribution.

Distribution of Sound-Pressure Levels for First Four Propeller Harmonics

The distribution of the sound-pressure levels of the first four propeller harmonics is shown in figure 5. Included in this figure are the measured levels and the levels obtained by the theory of reference 1.

The measured sound-pressure levels of the first two propeller harmonics (figs. 5(a) and 5(b)) show the unsymmetrical distribution displayed by the overall sound-pressure measurements, the highest levels being 120 decibels and 112 decibels for the first and second harmonics, respectively, in the right rear quadrant. Ahead of the propeller disk the sound-pressure level of the first harmonic dropped to 92 decibels. Measured sound-pressure levels of the second harmonic (fig. 5(b)) in the left forward quadrant are not shown. The attenuations necessary for the higher harmonics limit the decibel range for the analysis to 85 decibels. The second harmonic was masked out of the analysis since it was below this level.

The third harmonic (fig. 5(c)) did not display the unsymmetrical characteristics in the rear quadrants that were found in the overall and first two harmonic distributions. The highest sound-pressure levels were measured ahead of the propeller disk, the pattern being unsymmetrical with sound levels of 112 decibels at 60° and 93 decibels at 300° .

The sound-pressure-level distribution of the fourth harmonic (fig. 5(d)) was also unsymmetrical with high sound levels measured in the right front (60°) and left rear quadrant (240°), both having levels of 108 decibels.

The theoretical calculations of sound-pressure levels (fig. 5) show a symmetrical distribution about the axis of rotation; the location of the maximum level is 15° behind the propeller disk for the first harmonic and approaches the propeller disk for the higher harmonics. These calculations also show a sound level of zero at the nose (vortex noise not included). For the first and second harmonics, the maximum measured sound-pressure levels were obtained 15° behind the propeller disk and the levels were 5 and 2 decibels higher, respectively, than the theory predicts. For the higher harmonics (third and fourth), the measured values of sound pressures do not agree with the theory with respect to the location of the maximum level. Also, theory predicts maximum sound-pressure levels 10 and 13 decibels lower for the third and fourth harmonics, respectively, than the maximums measured.

Frequency spectra.- Figures 6 and 7 present the frequency spectra at stations extending from 240° (30° behind the propeller plane, left rear quadrant) clockwise through 120° (30° behind the propeller plane, right rear quadrant). The spectra at stations about the tail of the

airplane containing large amounts of self-generated overall noise are omitted. Two ranges of frequencies are covered in two separate frequency analyses. The high-frequency range (fig. 7) covers from 50 to 14,000 cycles per second. The high range is used to show approximately what noise level is contained in the high-frequency propeller and background noise. Propeller harmonics in this range are obscured because of the broad filter band used. The low-frequency range (fig. 6) is from 50 to 1,400 cycles per second and covers the first 12 propeller harmonics.

The general characteristics of the propeller noise shown in figures 6(a), 6(b), and 6(k) indicate that the higher levels of noise behind the propeller consist primarily of the low propeller harmonics. The level of the higher propeller harmonics is sufficiently low to be masked out of the analysis because of the attenuation necessary for the low propeller harmonics. In the plane of and ahead of the propeller (figs. 6(c) to 6(i)), the relative level for the higher propeller harmonics in relation to the lower propeller harmonics becomes greater. The second harmonic is sufficiently low so that it is masked out in the left forward quadrant at stations of 300° and 330° (figs. 6(d) and 6(e)) because of the attenuations necessary for the higher harmonics.

Effects of height on sound level.- The sound-pressure levels of the propeller noise in the first four propeller harmonics at heights of 0, 2, $3\frac{1}{2}$, and 5 feet above the ground at a location 270° clockwise from the nose are shown in figure 8.

The overall sound-pressure level varied 6 decibels with microphone height, being at its maximum ($115\frac{1}{2}$ decibels) at the ground and dropping to $109\frac{1}{2}$ decibels at $3\frac{1}{2}$ feet above the ground. The sound-pressure level of the first propeller harmonic was lowest at the ground; raising the microphone 5 feet increased the sound level 6 decibels. The sound-pressure level of the second and third harmonics had the highest levels on the ground; raising the microphone to 5 feet decreased the sound levels for the second and third harmonics 7 and 10 decibels, respectively. The sound level of the fourth harmonic varied 7 decibels in the range of heights investigated, the level being highest at the ground and at the 5-foot height and lowest at the 2- and $3\frac{1}{2}$ -foot heights.

The sound-level variations of the first four harmonics with height indicate that reflected waves in addition to the normal ground-reflected wave are present. These additional waves probably originate from the fuselage or wing. When the propeller is considered as a point source with only a ground-reflected wave and the free-space wave, all harmonics

should indicate a maximum (6 decibels above free space) at the ground and raising the microphone through the range of heights to 5 feet should produce no apparent change in sound level of the first harmonic, a decrease of approximately 3 decibels for the second harmonic, a decrease of approximately 6 decibels for the third harmonic, and a decrease of more than 6 decibels for the fourth harmonic.

The indication that multiple reflected waves may account for variation in the measured sound waves of the order of 6 decibels at one station also suggests that this phenomenon and the unsymmetrical protuberances about the nose of the airplane reflecting sound waves may be the cause of the measured unsymmetrical noise pattern.

CONCLUDING REMARKS

Sound-level measurements and tape recordings of the noise emitted from a 10-foot-diameter, four-blade propeller have been made at stations about the propeller at a 75-foot radius. The tape recordings at each station have been analyzed to obtain overall sound-pressure levels and frequency spectra.

Overall sound-pressure levels obtained by direct sound-level-meter readings and from tape recordings agree within 3 decibels. The overall sound-pressure level displayed an unsymmetrical distribution, the maximum sound-pressure level in the right rear quadrant being 5 decibels higher than the level in the left rear quadrant.

The distribution of the sound-pressure levels of the first four propeller harmonics shows that the unsymmetrical distribution of noise in the rear quadrant is due primarily to an unsymmetrical distribution of the level of the first two propeller harmonics. Higher harmonics also display an unsymmetrical distribution but the maximum levels in the left rear quadrants are sufficiently low so as not to influence the overall sound-level distribution. The frequency analyses show that the highest levels of noise, behind the plane of the propeller, consist primarily of the lower propeller harmonics. In the plane of and ahead of the propeller, however, harmonics as high as the eleventh are important.

The theoretical calculation by the method used in NACA TN 2968 predicts accurately, for the 10-foot propeller investigated, the location of and the maximum sound-pressure levels to be expected for the overall noise and the first two propeller harmonics. The calculations do not predict accurately the location of the maximum sound-pressure levels and the calculated maximum levels are 10 and 13 decibels lower than the maximum measured levels for the third and fourth harmonics, respectively.

The harmonic analysis of the tape recordings obtained at varied heights, at one station, indicates the presence of strong reflected waves in addition to the normally expected ground-reflected wave. Partial cancellation of the direct wave by the reflected wave or waves lowered the noise level of the first propeller harmonic by 6 decibels at the ground level. The higher harmonics also displayed variations not expected of the free-space-wave and ground-wave combination.

The existence of multiple reflected waves and the unsymmetrical protuberances about the nose of the airplane which reflect sound waves are possible explanations of the unsymmetrical distribution of sound levels measured in the present investigation.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 6, 1955.

REFERENCE

1. Hubbard, Harvey H.: Propeller-Noise Charts for Transport Airplanes. NACA TN 2968, 1953.

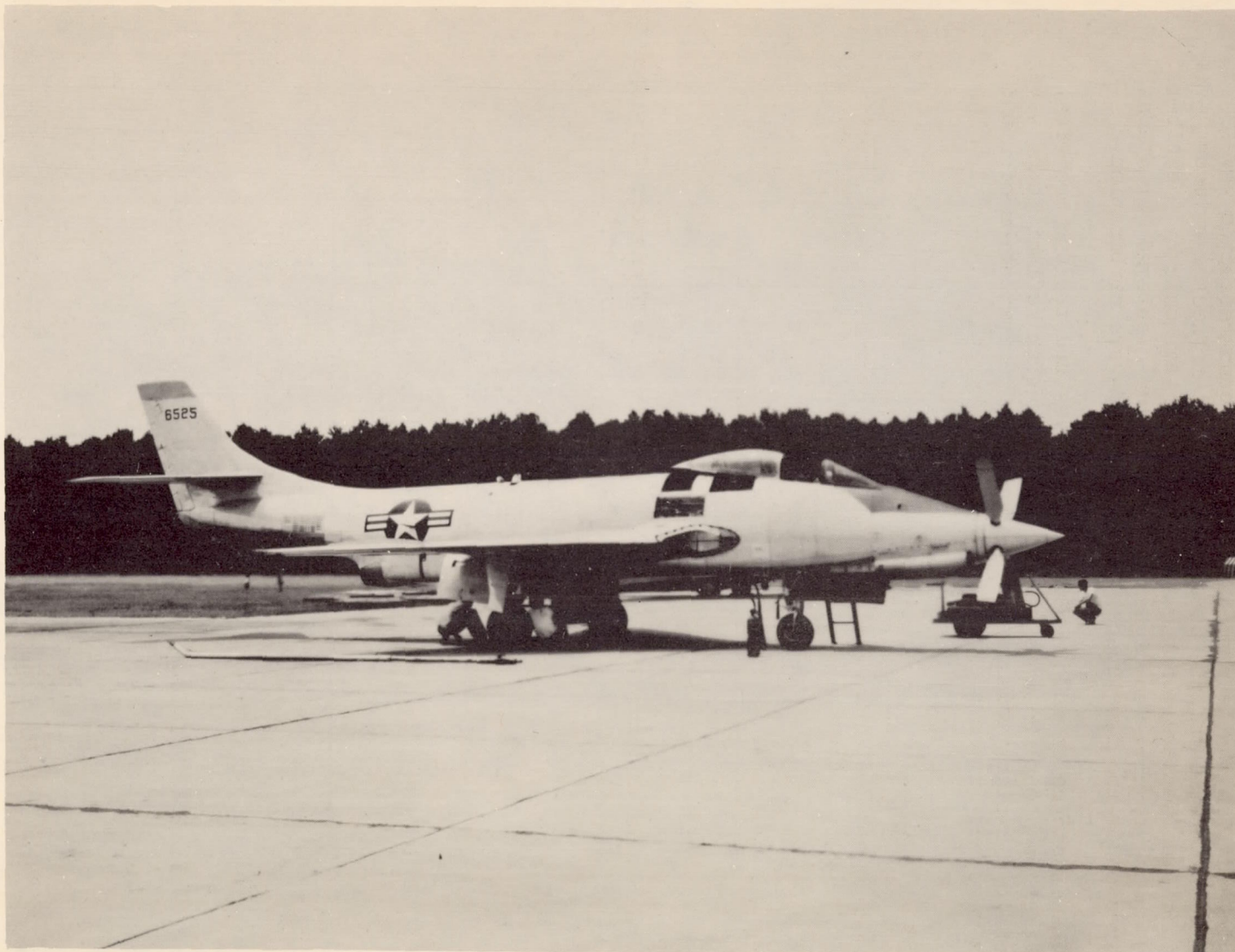


Figure 1.- The 10-foot-diameter, four-blade propeller investigated mounted
on the test airplane.

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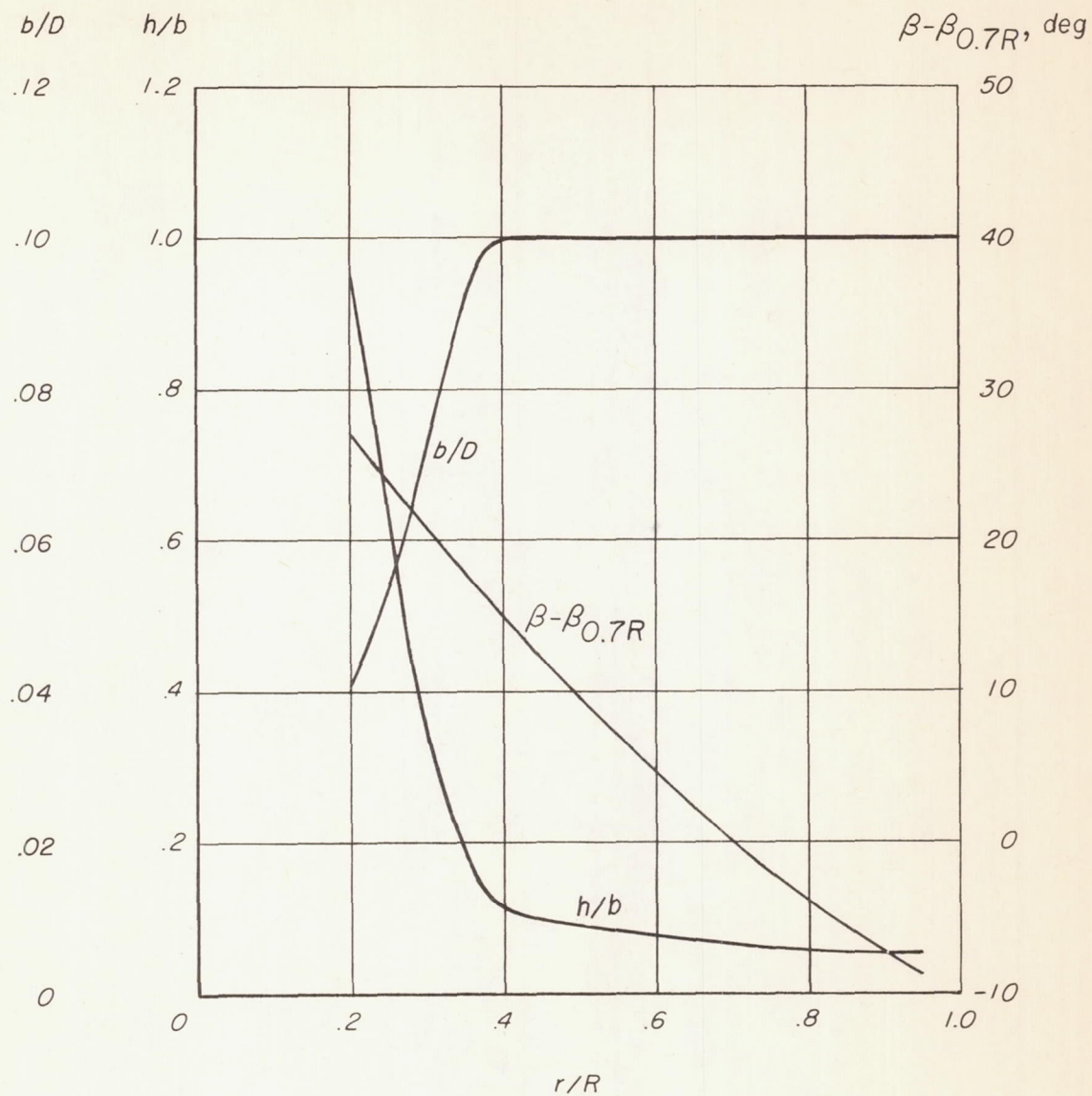
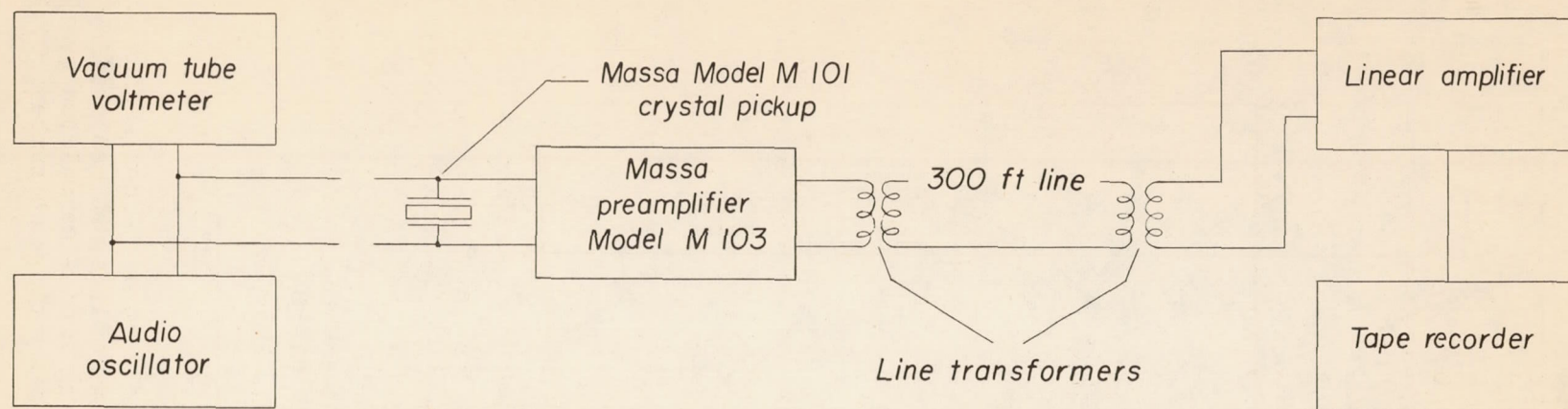
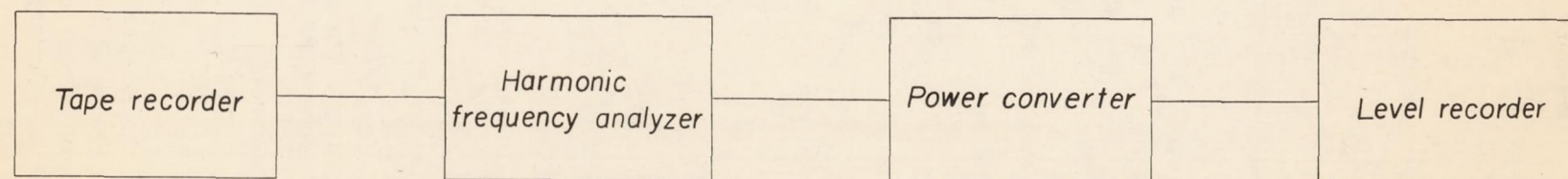


Figure 2.- Blade-form curves of the 10-foot-diameter, four-blade propeller used in the present investigation.



(a) Sound recording and calibrating equipment.



Filter band width at half-power level
 0 - 1,500 cps range, 20 cps
 0 - 15,000 cps range, 200 cps

(b) Sound analyzing equipment.

Figure 3.- Block diagrams of the recording and analyzing equipment used in the investigation.

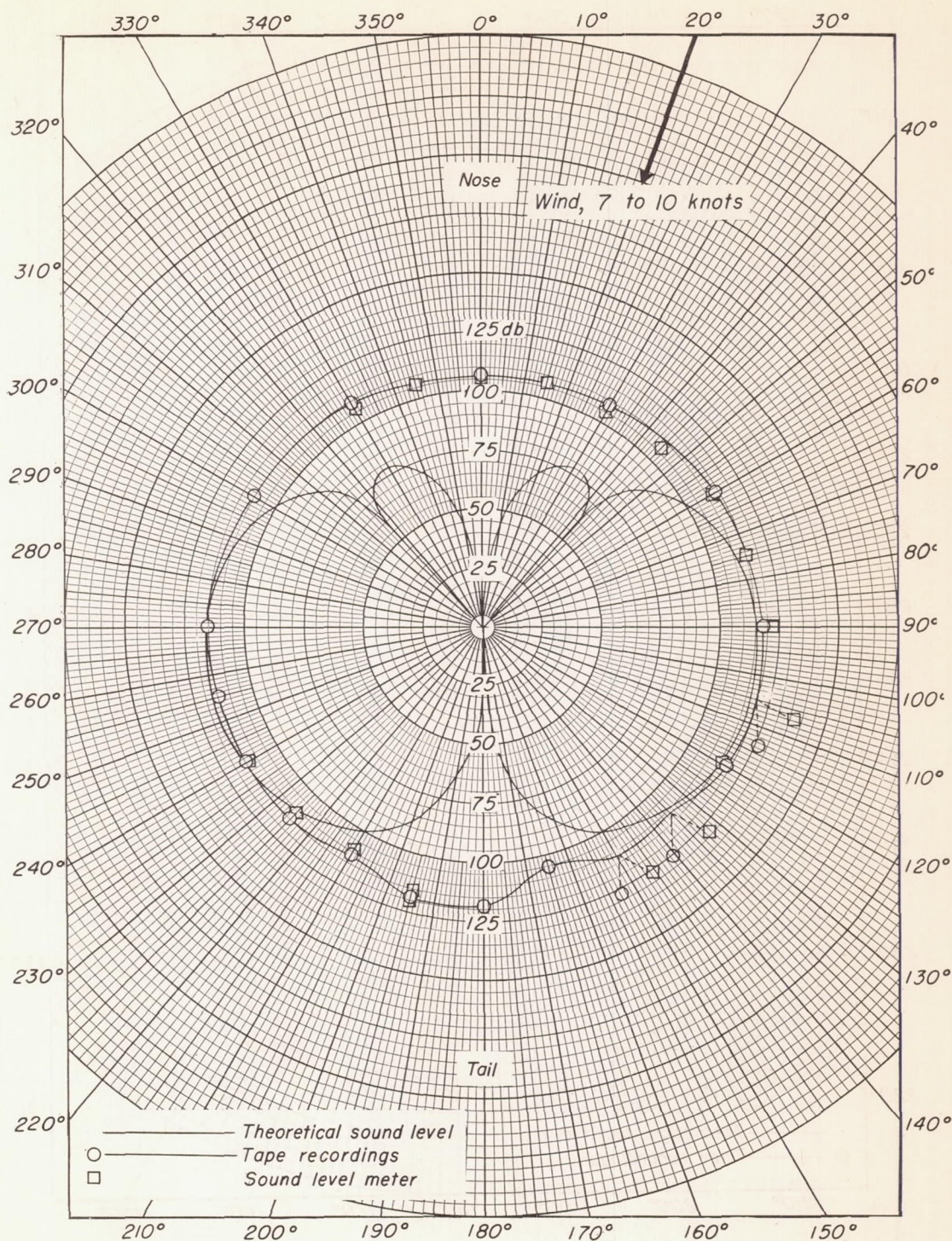
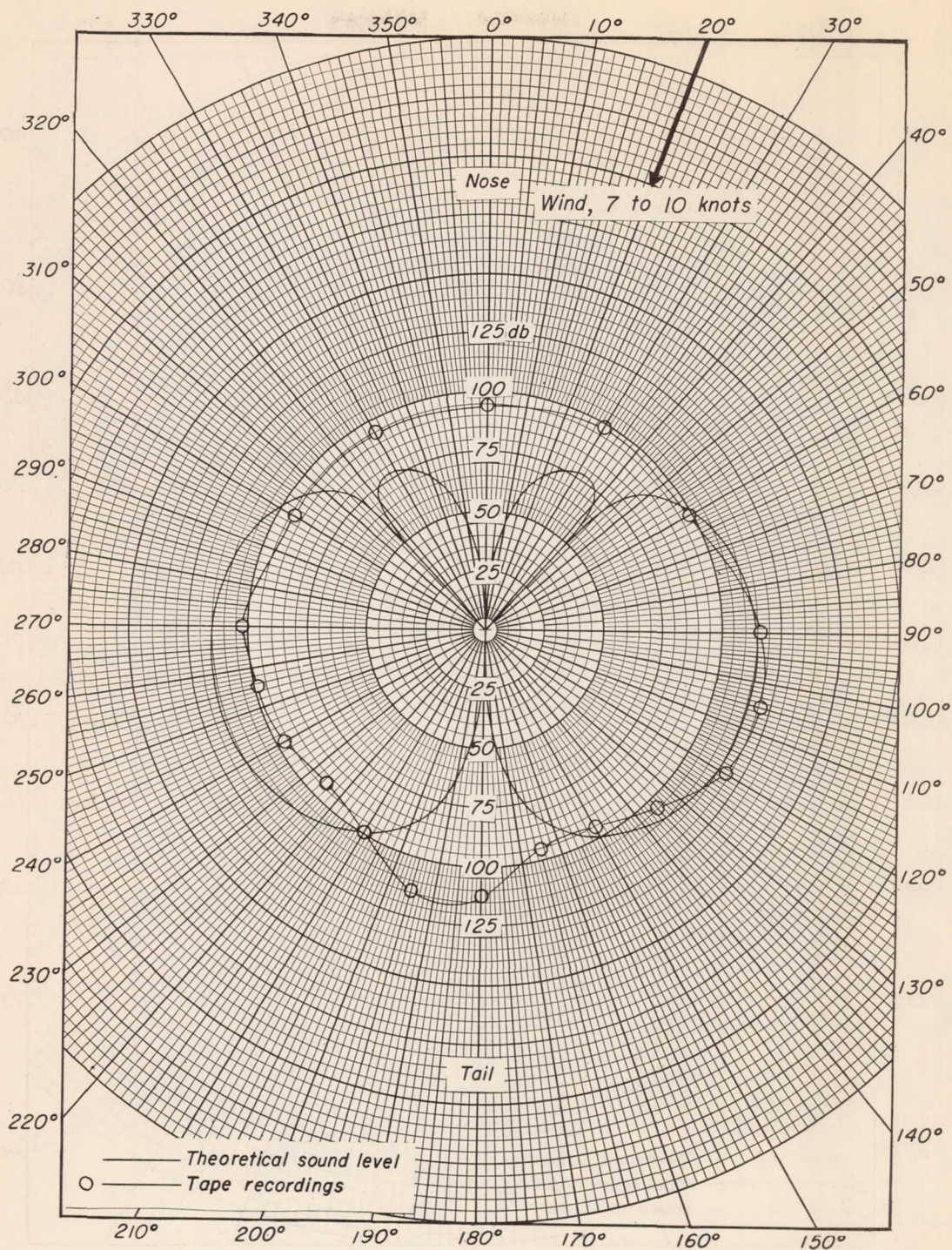
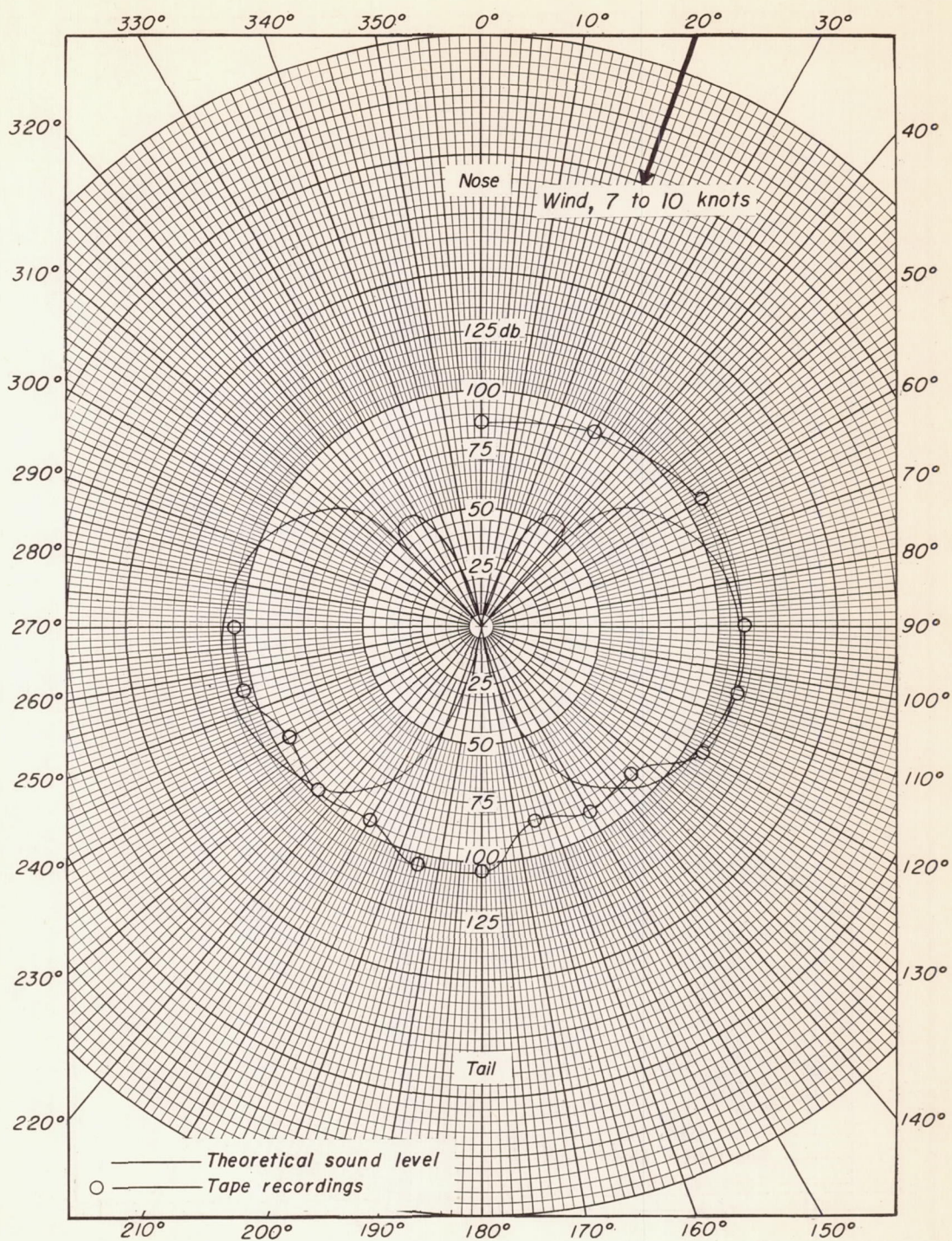


Figure 4.- The overall sound-pressure levels at a 75-foot radius as obtained by the analysis of the tape recordings, as measured by the General Radio Company sound-level meter, and as calculated by the theory of reference 1. Horsepower, 1,250; tip Mach number, 0.79.



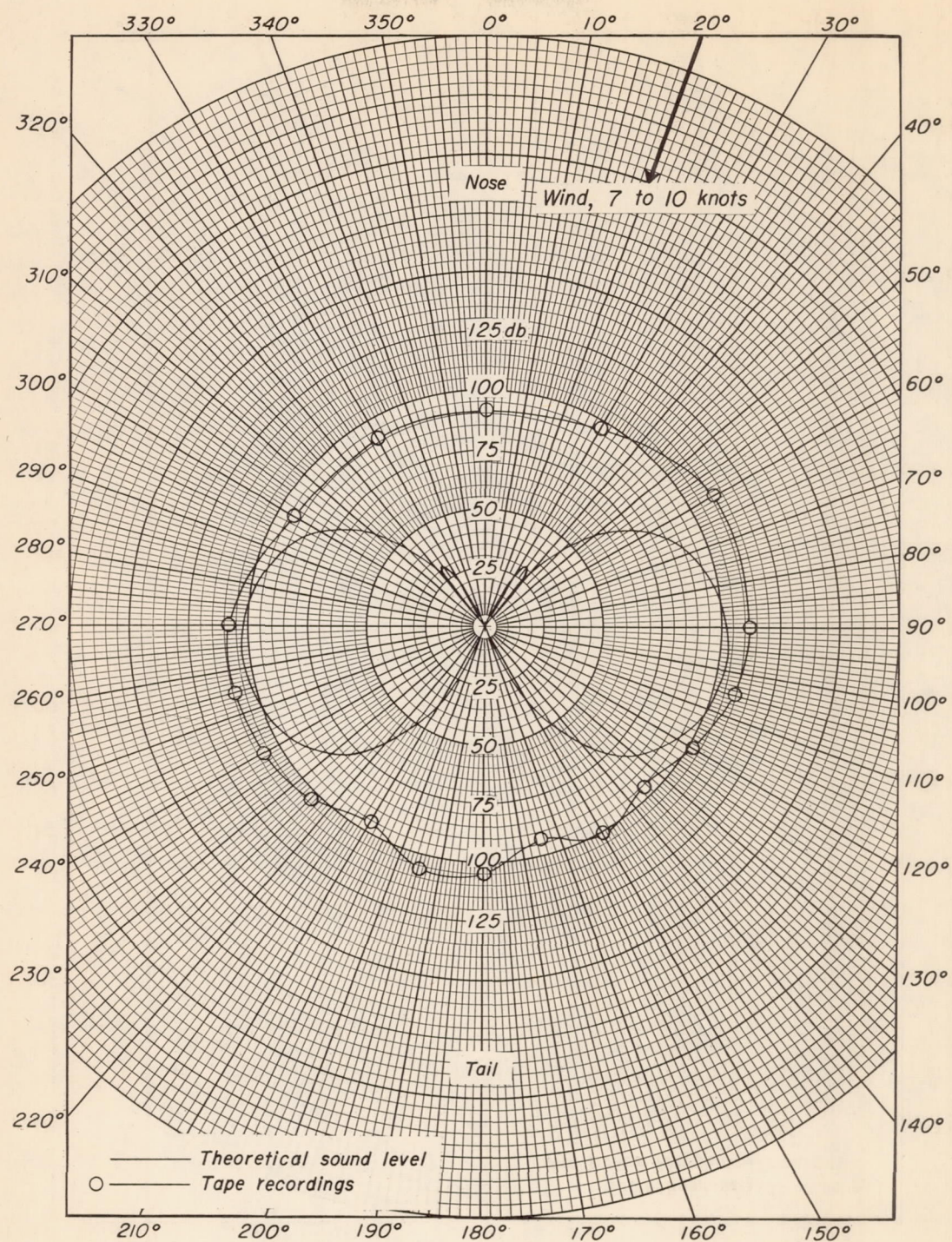
(a) First propeller harmonic (fundamental).

Figure 5.- The sound-pressure levels at a 75-foot radius as obtained by the analysis of the tape recordings and as calculated by the theory of reference 1. Horsepower, 1,250; tip Mach number, 0.79.



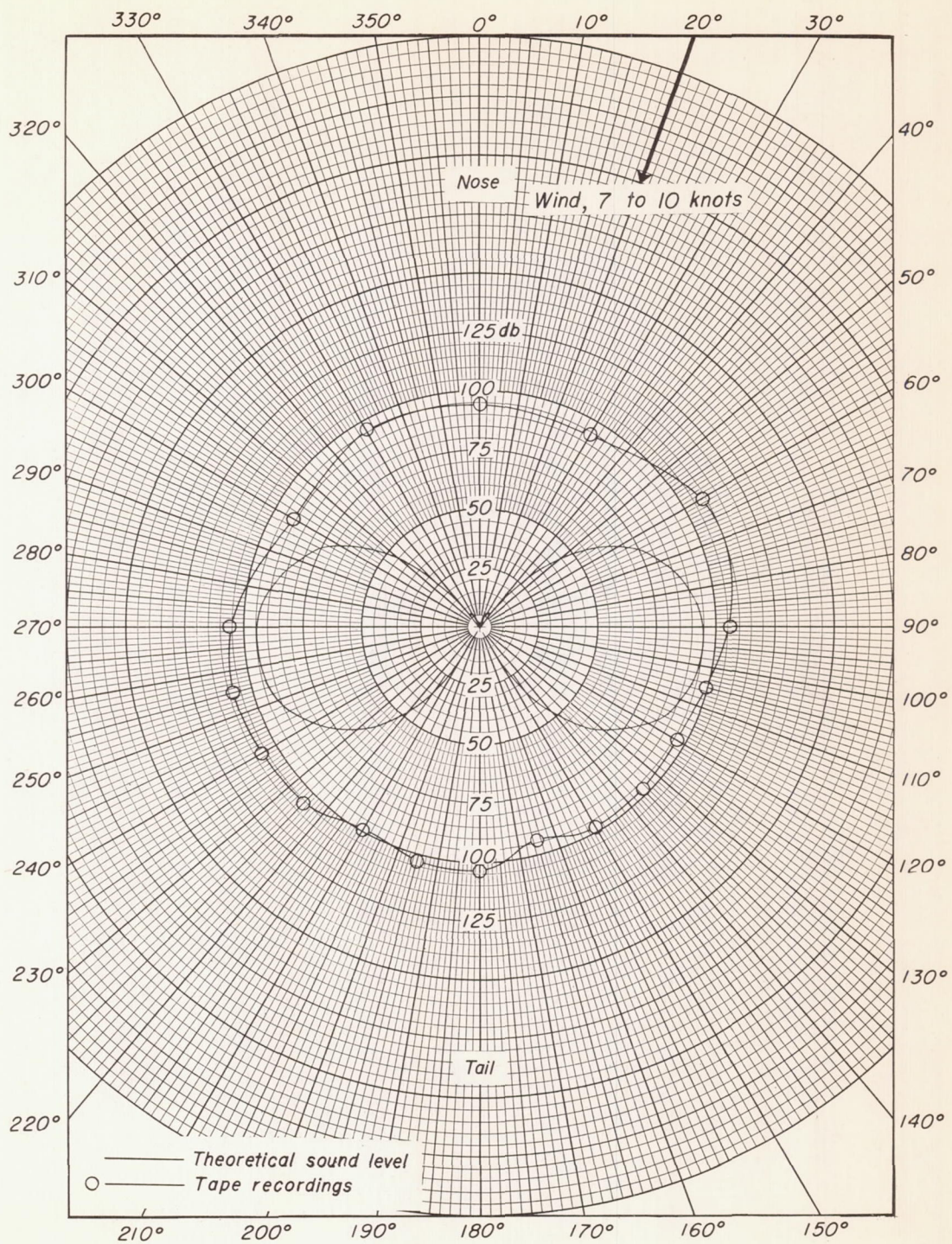
(b) Second propeller harmonic.

Figure 5.- Continued.



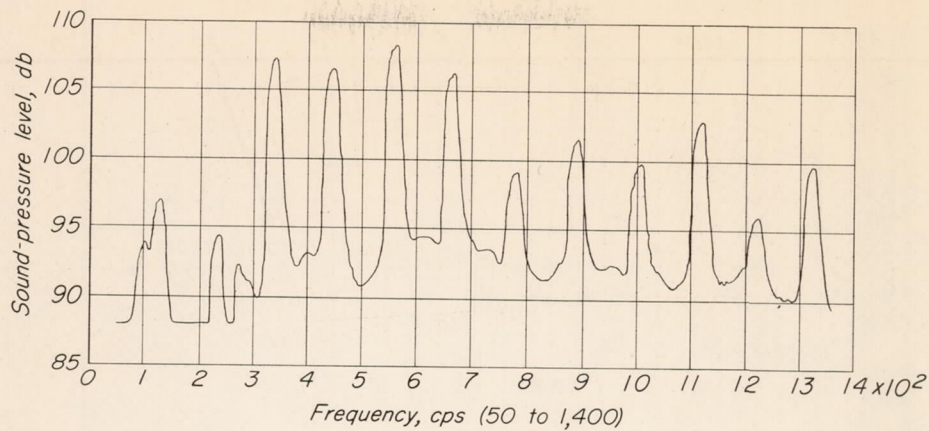
(c) Third propeller harmonic.

Figure 5.- Continued.

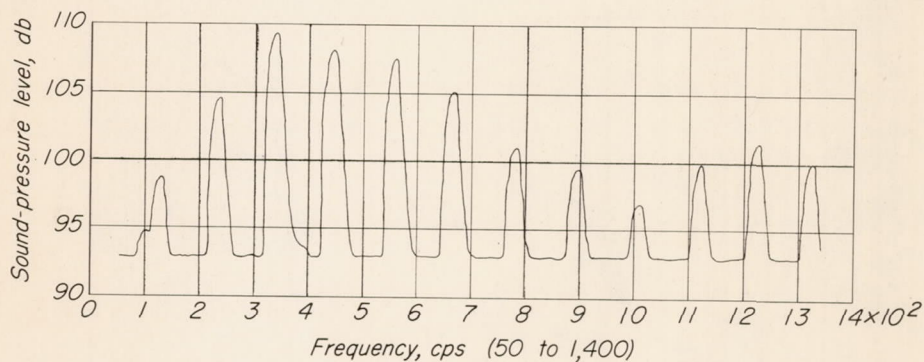


(d) Fourth propeller harmonic.

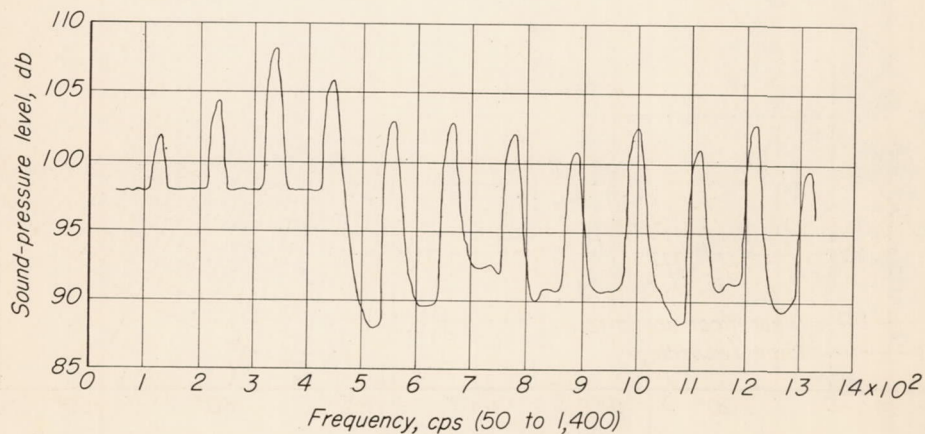
Figure 5.- Concluded.



(a) Station 240° clockwise from nose.

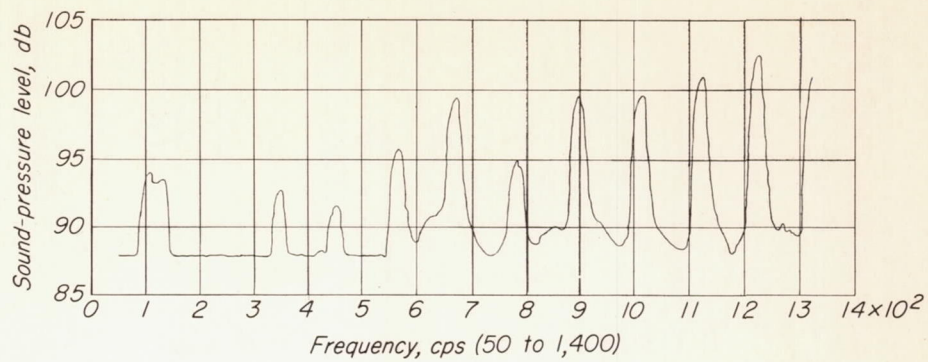


(b) Station 255° clockwise from nose.

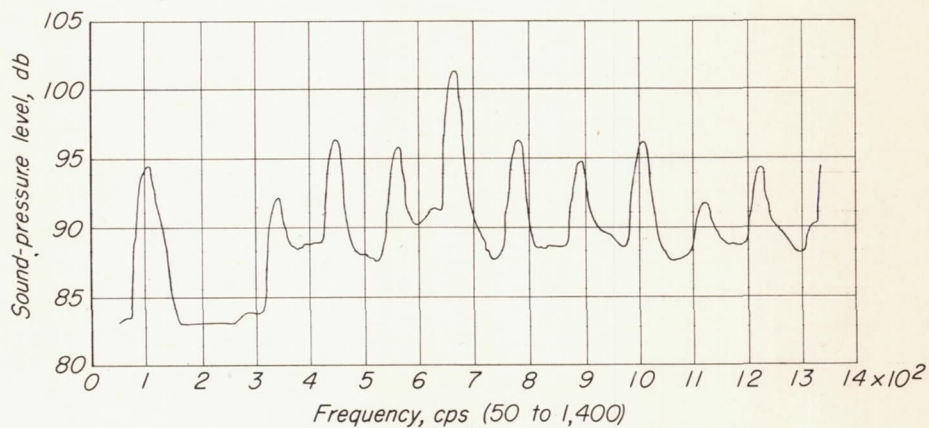


(c) Station 270° clockwise from nose.

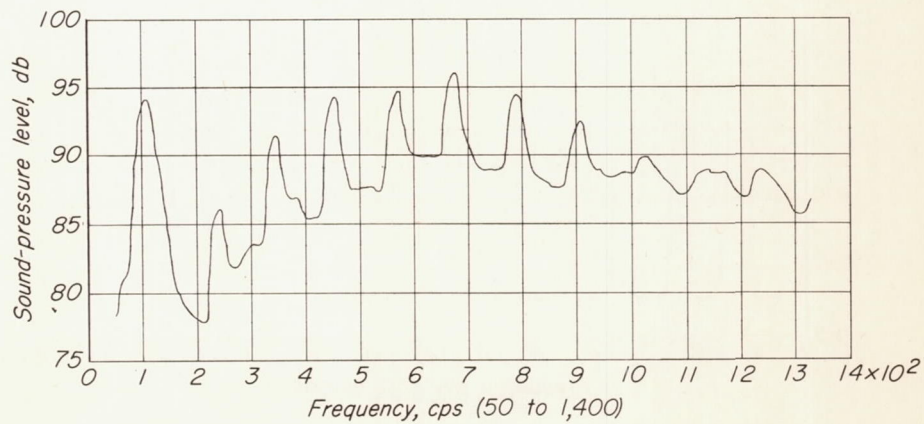
Figure 6.- Variation of sound-pressure levels with frequency for a range of 50 to 1,400 cycles per second and a filter band width of 20 cycles per second. Fundamental blade passage frequency, 111.7 cycles per second.



(d) Station 300° clockwise from nose.

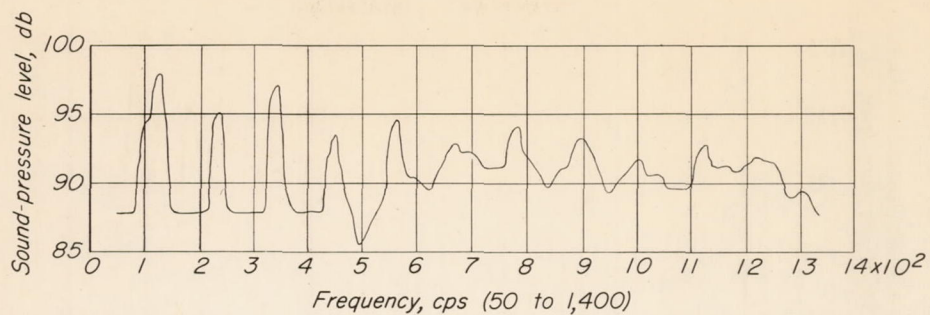


(e) Station 330° clockwise from nose.

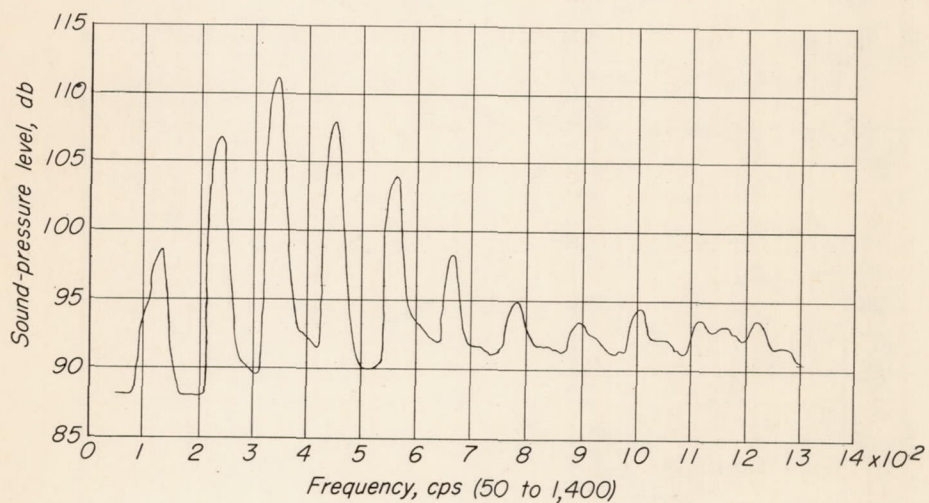


(f) Station 0° clockwise from nose.

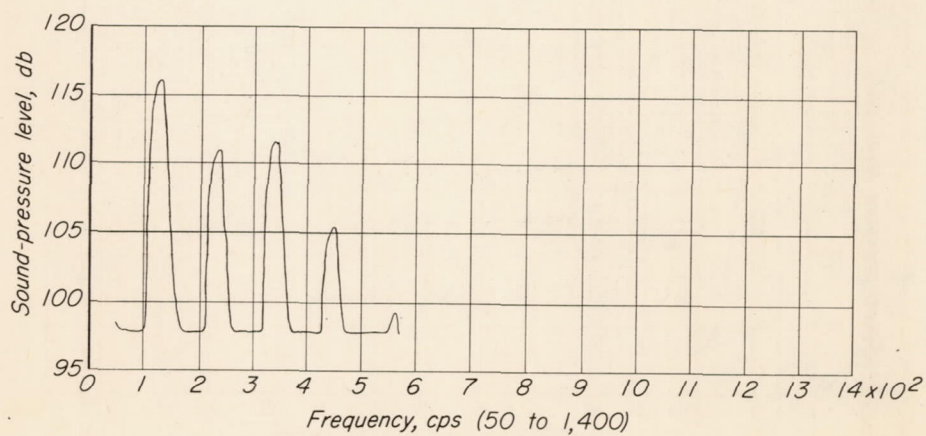
Figure 6.- Continued.



(g) Station 30° clockwise from nose.

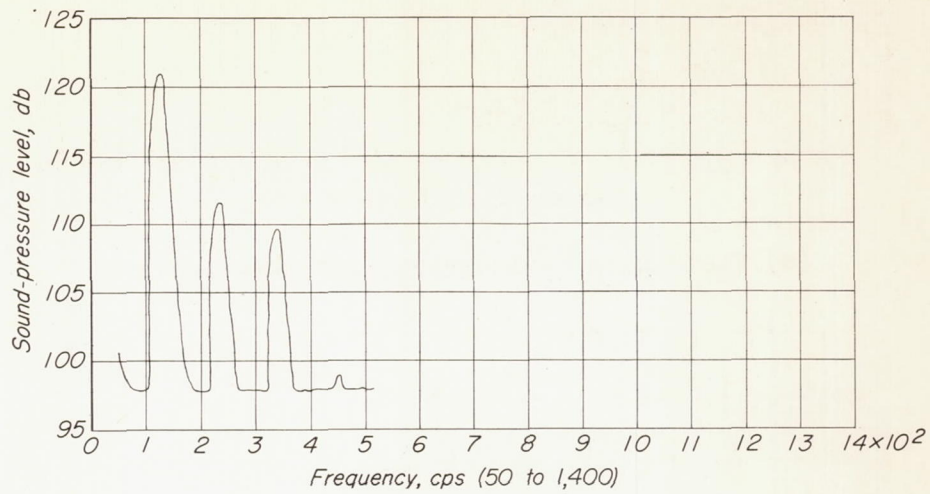


(h) Station 60° clockwise from nose.

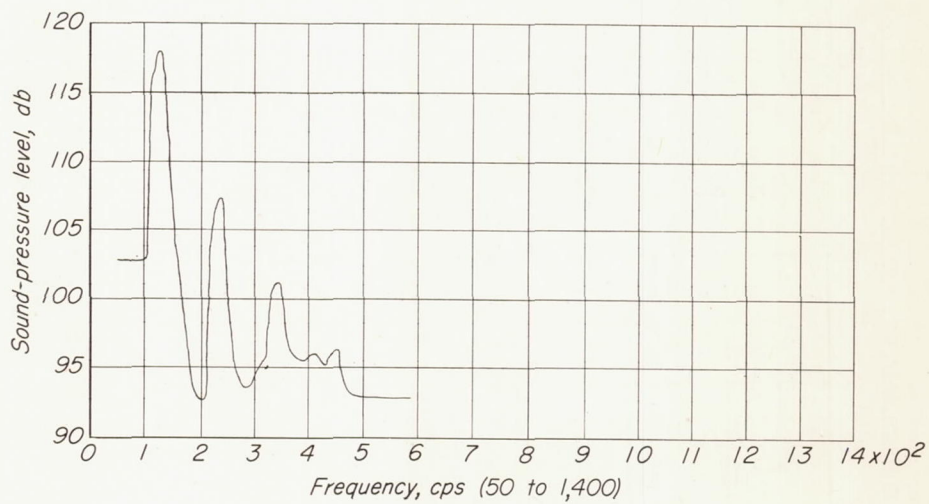


(i) Station 90° clockwise from nose.

Figure 6.- Continued.

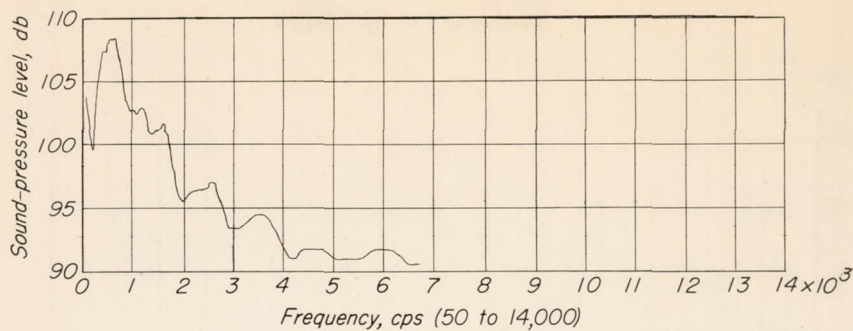


(j) Station 105° clockwise from nose.

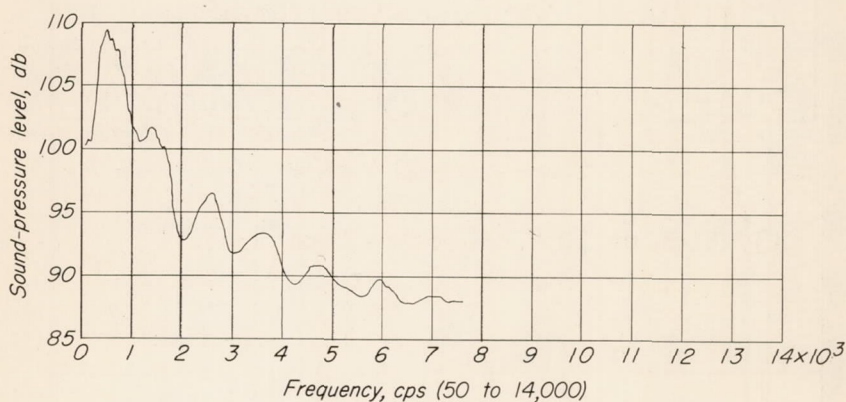


(k) Station 120° clockwise from nose.

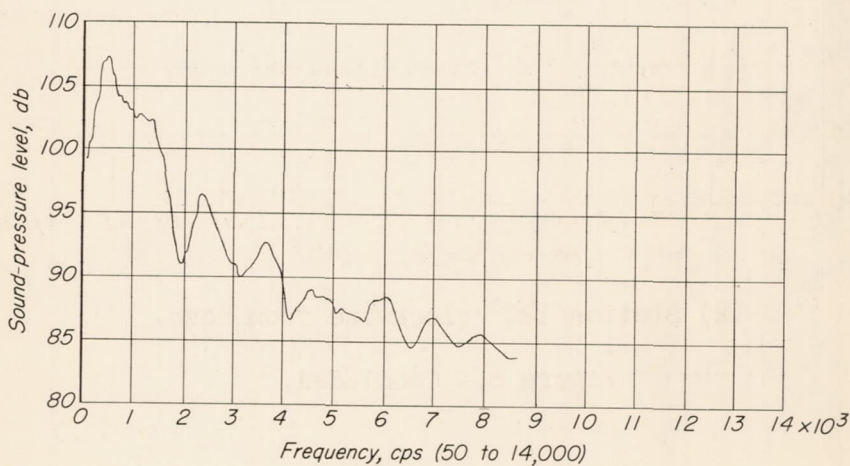
Figure 6.- Concluded.



(a) Station 240° clockwise from nose.

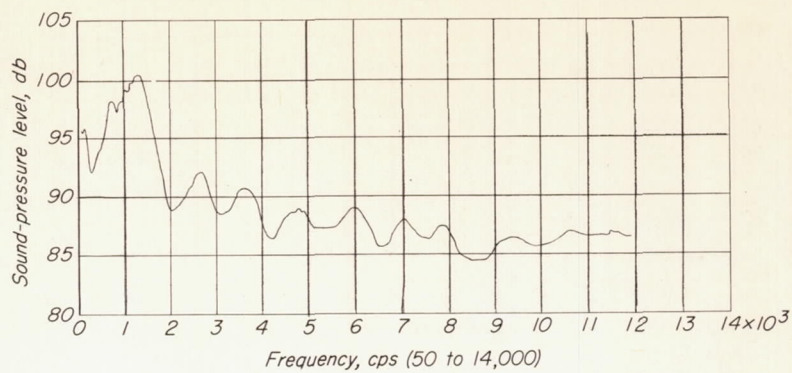


(b) Station 255° clockwise from nose.

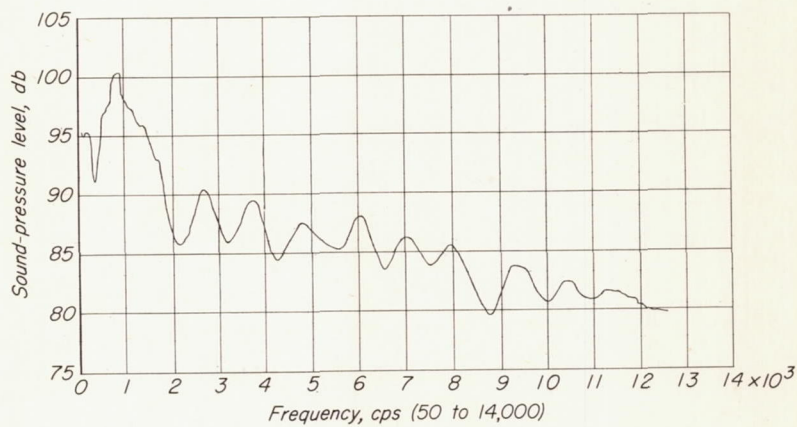


(c) Station 270° clockwise from nose.

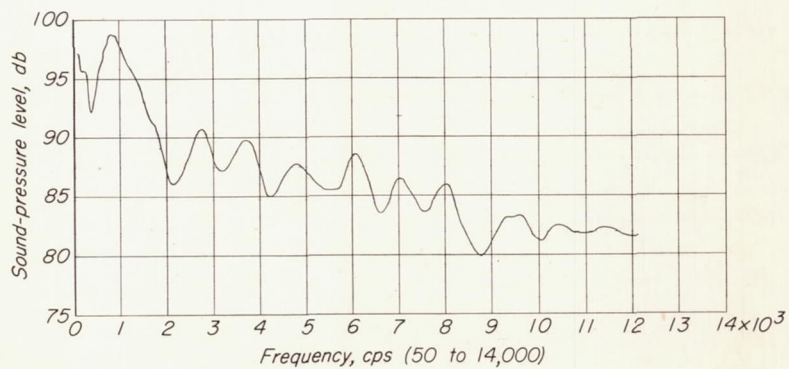
Figure 7.- Variation of sound-pressure levels with frequency for a range of 50 to 14,000 cycles per second and a filter band width of 200 cycles per second. Fundamental blade passage frequency, 111.7 cycles per second.



(d) Station 300° clockwise from nose.

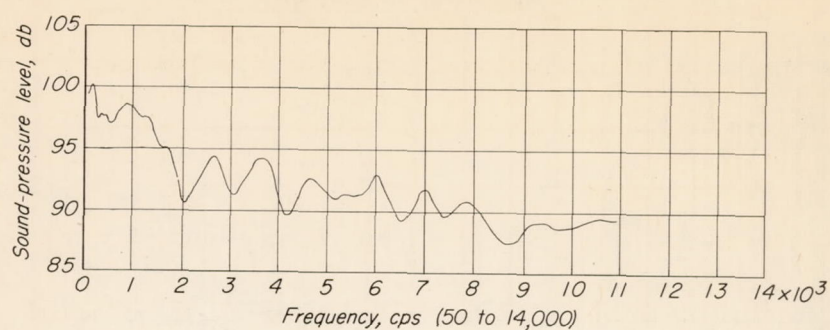


(e) Station 330° clockwise from nose.

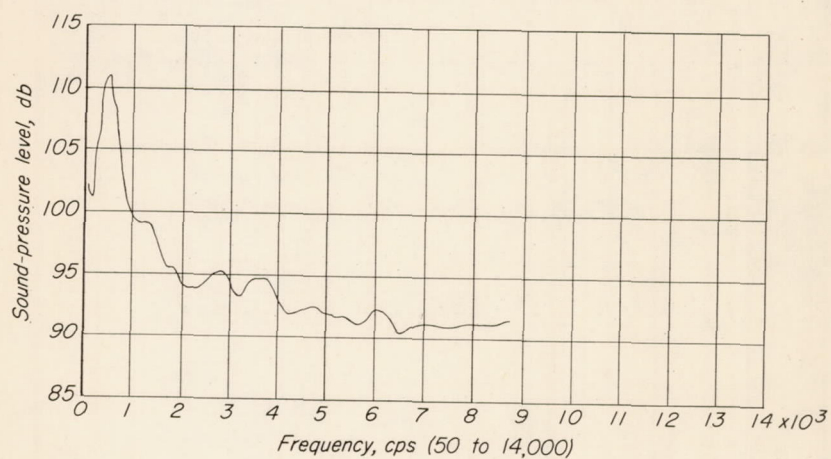


(f) Station 0° clockwise from nose.

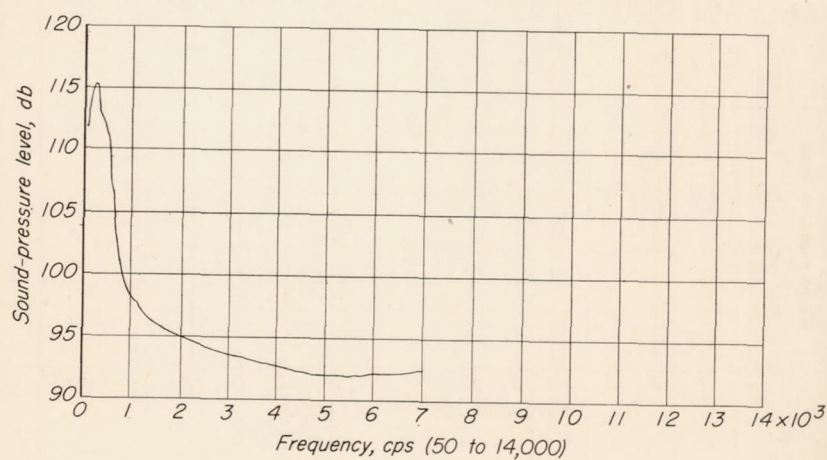
Figure 7.- Continued.



(g) Station 30° clockwise from nose.

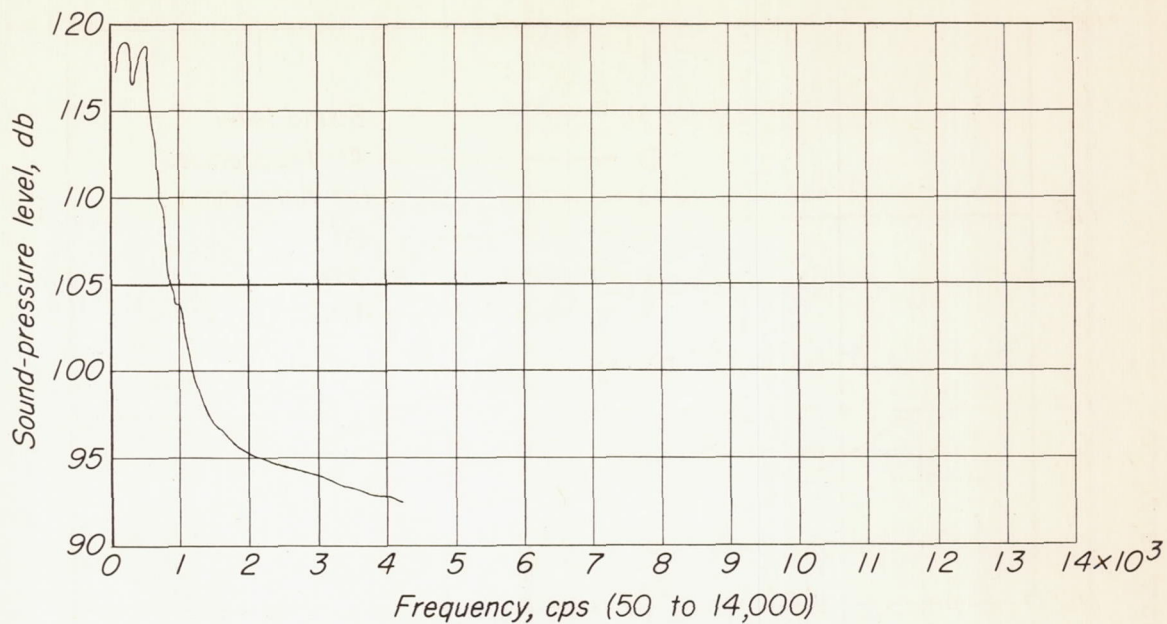


(h) Station 60° clockwise from nose.

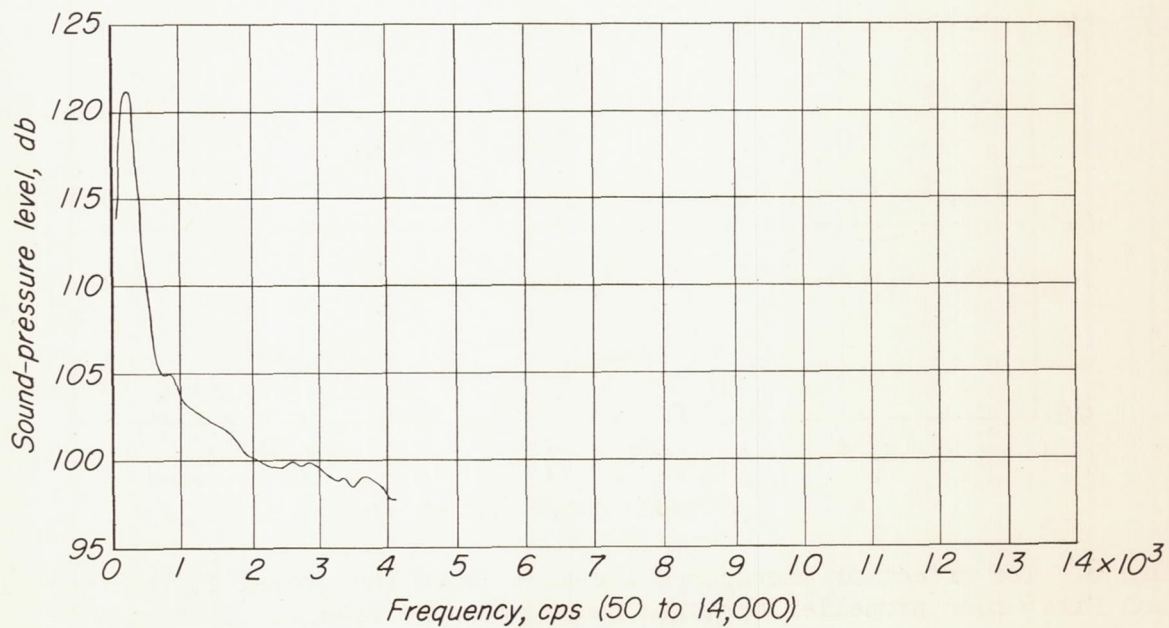


(i) Station 90° clockwise from nose.

Figure 7.- Continued.



(j) Station 105° clockwise from nose.



(k) Station 120° clockwise from nose.

Figure 7.- Concluded.

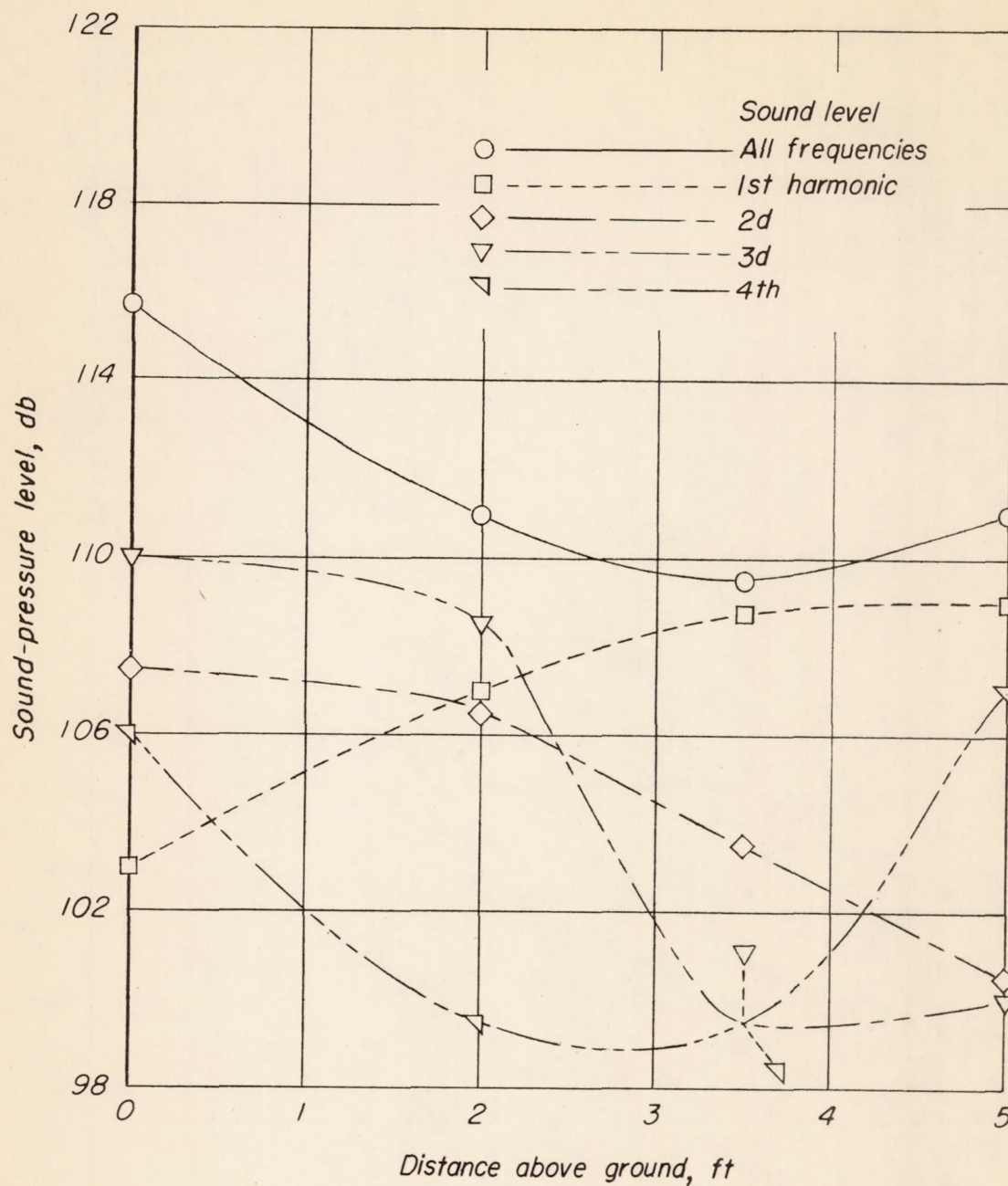


Figure 8.- The effect of microphone distance above the ground on the overall and first four propeller harmonic sound-pressure levels. Station 270°.